

29 AUG 1962

SPECIAL REPORT

MEASUREMENTS OF ELECTROSTATIC CHARGES ON MEN AND WOMEN IN VARIOUS CLOTHES

November 1961

0395-03(08)SP

Investigation under U. S. Army Chemical Center
Contract No. DA-18-108-405-CML-829

ORDNANCE DIVISION

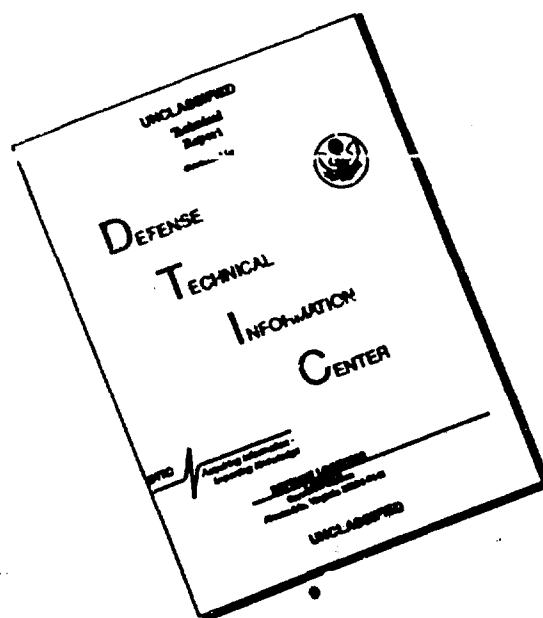
Aerjet-General
CORPORATION

A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY
AZUSA, SACRAMENTO, AND DOWNEY, CALIFORNIA

PROPERTY OF U. S. ARMY
CHEMICAL RESEARCH AND
DEVELOPMENT LABORATORIES
TERRYVILLE, MARYLAND
ARMY CHEMICAL CENTER
MARYLAND

30

DISCLAIMER NOTICE



**THIS DOCUMENT IS BEST
QUALITY AVAILABLE. THE COPY
FURNISHED TO DTIC CONTAINED
A SIGNIFICANT NUMBER OF
PAGES WHICH DO NOT
REPRODUCE LEGIBLY.**

29 AUG 1962

AEROJET-GENERAL CORPORATION
Ordnance Division
11711 Woodruff Avenue
Downey, California

SPECIAL REPORT

MEASUREMENTS OF ELECTROSTATIC CHARGES ON MEN AND WOMEN
IN VARIOUS CLOTHES

0395-03(08)SP

by

T. G. Owe Berg, G. C. Fernish, and Margaret J. Hunkins

Investigation under U. S. Army Chemical Center
Contract No. DA-18-108-405-CML-829

This document has been approved for public release and
sale, its distribution is unlimited.

Approved by:

L. Zernow

L. Zernow, Director of
Research, Ordnance Div.

L. Zernow for

G. C. Throne, Manager
Ordnance Division

Date: 2 November 1961

No. of Pages: 24

Classification: UNCLASSIFIED

COPY NO. 8

PROPERTY OF U. S. ARMY
CHEMICAL RESEARCH AND
DEVELOPMENT LABORATORIES
TRICORP
APC, CHEMICAL CENTER
MARIETTA

MEASUREMENTS OF ELECTROSTATIC CHARGES ON MEN AND WOMEN IN
VARIOUS CLOTHES

T. G. Owe Berg, G. C. Fernish, and Margaret J. Hunkins

ABSTRACT

Electrostatic charges have been measured on 100 men and 100 women in the uniforms of the Marines and the Women Marines and also with men and women in civilian clothes. The charges measured vary by 3 orders of magnitude depending upon the fabric worn. Cotton and wool give comparatively small charges; synthetic fabrics (dacron, orlon, nylon) give comparatively large charges.

Charges are generated as a result of sliding contact between garments or between garment and skin, followed by separation. This occurs at the cuffs of trousers and at the hem of a skirt. Other garments contribute negligibly to the charge.

CONTENTS

	<u>Page No.</u>
1. INTRODUCTION	1
2. EXPERIMENTAL TECHNIQUE	1
3. EXPERIMENTAL RESULTS.	7
4. SETTLING OF AEROSOL OF CHARGED PERSONS.	19
5. DISCUSSION	19
6. CONCLUSION	22

FOREWORD

Reproduction of this document in whole or in part is prohibited except with permission of Commanding Officer, Edgewood Arsenal, ATTN: SMUEA-TSTI-TR, Edgewood Arsenal, Maryland 21010; however, DDC is authorized to reproduce the document for United States Government purposes.

The information in this report has been cleared for release to the general public.

1. INTRODUCTION

It is well known that a person may acquire considerable electrostatic charge under a variety of conditions, e. g., walking on an insulated floor, sliding across the seat of an automobile, combing the hair, taking off silk or nylon garments. The charge acquired is frequently large enough to be bothersome and may in certain activities constitute a hazard. The conditions favoring generation of large charges are fairly well known in a qualitative way, but there seems to be no quantitative information on the subject.

It is conceivable that electrostatic charge may affect the deposition of aerosols on military personnel. This effect was mentioned by Eipper and Woodson*, who measured the relative amounts of aerosol deposited on different military fabrics. They observed that treatment of one fabric with an antistatic compound reduced the amount of aerosol deposited. As would be expected in a case of electrostatic forces, the effect of this treatment was greatest at small velocities of the aerosol. The charges were not measured.

The effect of electrostatic charge upon the settling of aerosols on military personnel has been studied quantitatively in an investigation that forms the subject of this report. This work has been directed primarily to the measurement of charge on military and civilian personnel as affected by clothes and state of motion. An exploratory experiment has been performed with settling of charged powder on highly-charged personnel.

2. EXPERIMENTAL TECHNIQUE

The electrostatic charge was measured with a Faraday cage and a recording electrometer. Figure 1 shows the design of the Faraday cage. It is constructed as a frame of 4 x 4 in. lumber that is covered with screen on both sides such that two parallelepipedic boxes are formed, one inside the other. In order to secure adequate insulation between the two, porcelain insulators about 1.25-in. high were inserted as shown in Figure 1. The dimensions are 36 x 36 x 78 in. inside and 46 x 46 x 88 in. outside. The inside floor is a 1/2 in. aluminum plate screwed to the wooden structure along its edge and also to two 2 x 4 in. beams across. One of the sides opens as a door and serves as entrance. The insulation resistance is between 10^{10} and $10^{11} \Omega$.

* J. E. Eipper and G. S. Woodson, Aerosol Deposition on Military Textiles, U. S. Army Chemical Warfare Labs., Techn. Rept. No. CWLR 2162, 1957.

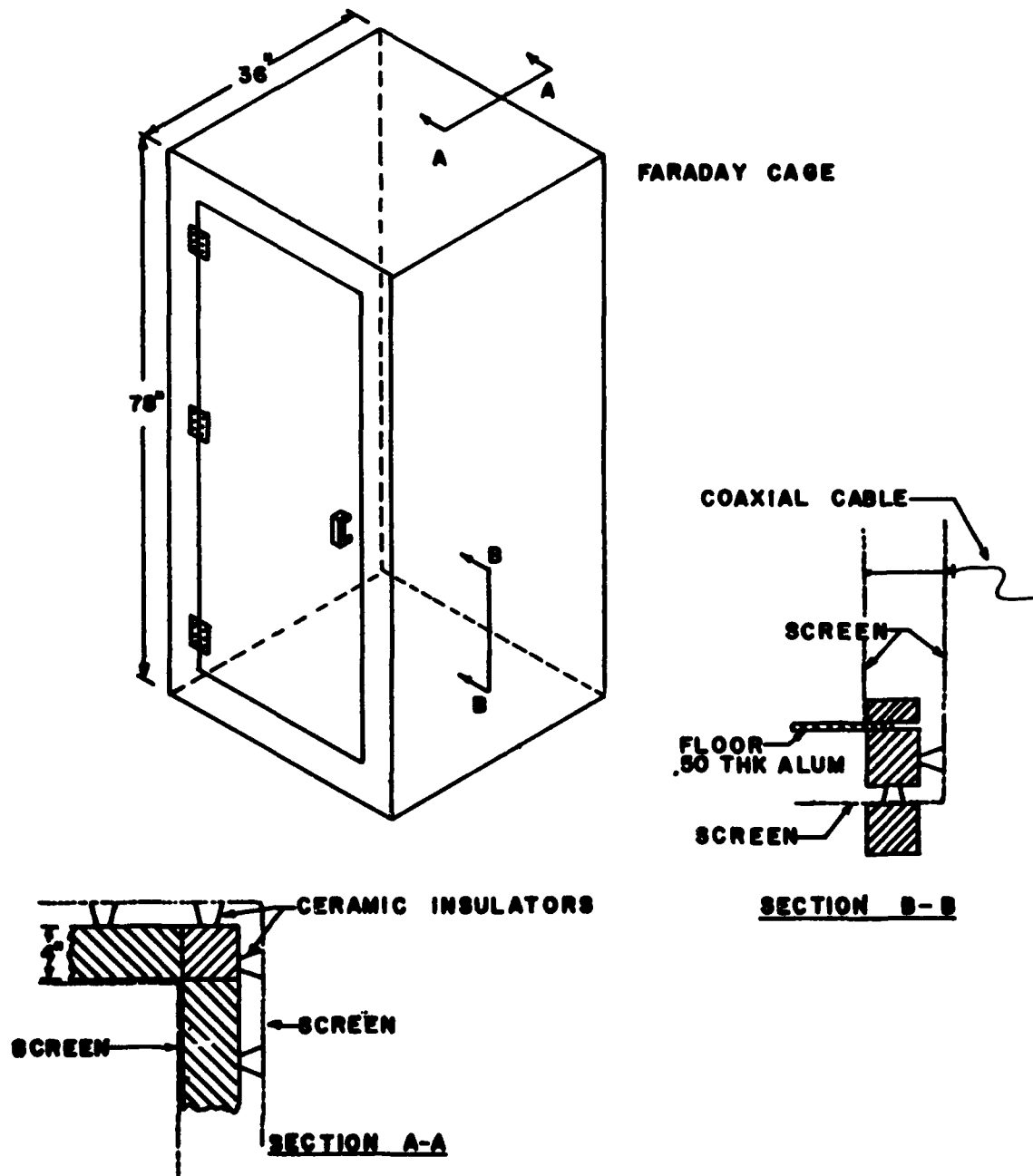


Figure 1. Faraday cage.

The recording electrometer used in these experiments is a General Radio dc amplifier together with an Esterline-Angus recorder. The amplifier is connected to the Faraday cage by a 3-ft coaxial cable. The total capacitance of Faraday cage and amplifier as determined from decay measurements is 2.6×10^{-9} F. The amplifier has a selector switch that gives 6 ranges for full deflection, 0.03, 0.1, 0.3, 1, 3, and 10 volts. The normal setting was 3 volts. Occasionally, the charge was too large for the instrument, and the sensitivity was then reduced by adding a capacitance of 2μ F. The input resistance of the amplifier was set at $10^9 \Omega$, which gives a time constant of 2.6 seconds with the 2.6×10^{-9} F capacitance and 2000 seconds with the 2μ F capacitance. In order to remove the charge from the cage and prepare for the next measurement, a push-button was installed that connects the two screens.

When a charge is suddenly introduced into the Faraday cage and later suddenly taken out again, the record should have the form shown in Figure 2. The actual records may differ from this ideal record in several respects. With a large time constant of the electrometer input circuit, the deflection increases gradually to the peak value. At the same time, discharge occurs. The error caused by this effect is considered negligible at the side of fortuitous variations in the magnitude of the charge. Occasionally the test object loses charge or picks up charge in the cage and may even reverse the polarity. The relevant quantity being the charge at entrance, this effect has no bearing upon this investigation, although it bears upon the mechanism of charge regeneration. Actual records are reproduced in Figures 3 and 4.

The charge being generated in friction, which is hardly reproducible, one should expect large variations in the charge recorded in repeated measurements. This view was borne out by preliminary laboratory experiments.

In order to obtain meaningful data it is therefore necessary to perform a large number of measurements and to treat the results statistically. It appears that more information could be derived from measurements with a large number of individuals than from a large number of measurements with one or a few individuals.

The equipment was first tested in the laboratory and then taken to Camp Pendleton where 100 men and 100 women were made available as test objects. (Data obtained with 75 men only are reported.) The measurements with the men were conducted in their gymnasium that has a concrete floor. The measurements with the women were conducted in their recreation building that has a hardwood floor.

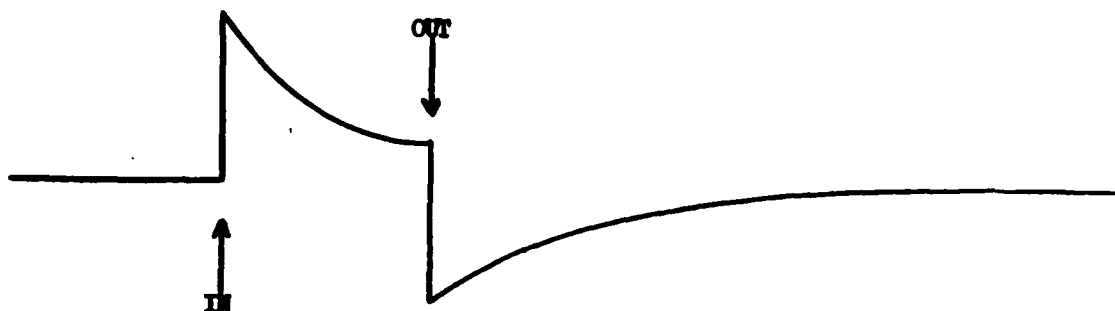


Figure 2. Ideal record of voltage on Faraday cage when a charge is brought into the cage and then suddenly taken out.

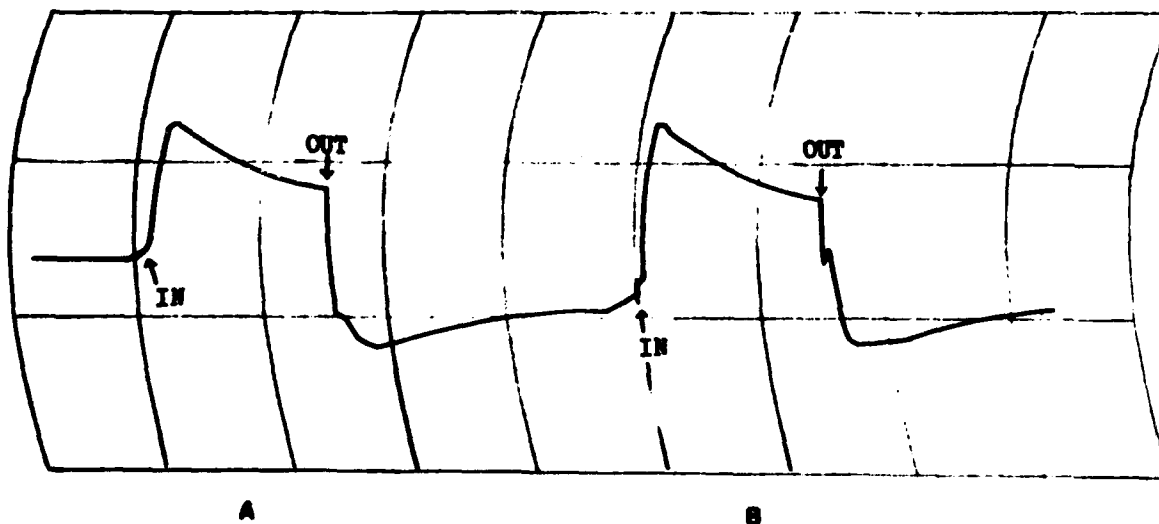


Figure 3. Typical record of man entering the cage from a standing position. Instrument setting $10^9 \Omega$, 3 volts; chart speed 6 in./min.

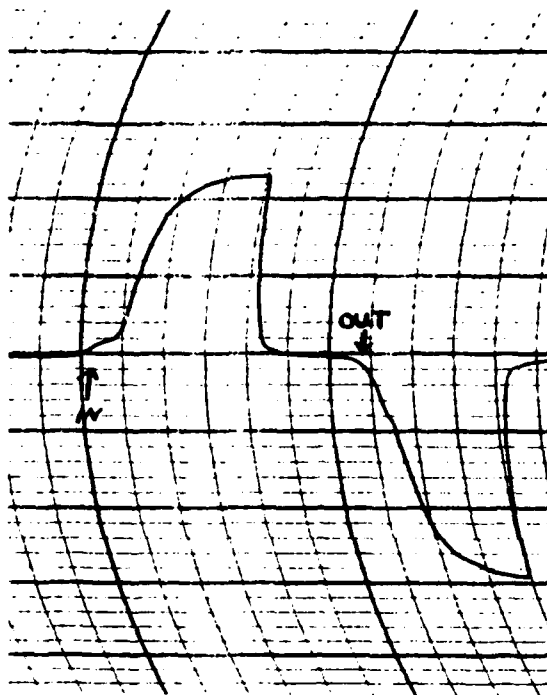


Figure 4. Typical record of woman in uniform entering the cage from a standing position. Instrument setting $10^9 \Omega$, 0.3 volts, $2 \mu F$; chart speed 6 in. /min.

The men and the women were dressed in their normal uniforms. The men wore the battle dress, which is a green cotton fabric, boots, helmet, and bayonet. The women wore a dress of green dacron, mixed with cotton, and regulation shoes. Three measurements were made, namely, entrance into the cage from standing, from walking, and from running.

Among the 100 men and 100 women, 10 were picked and used for testing the dependence of the charge upon the clothes worn. The men were dressed in battle dress with various accessories, namely,

<u>Test</u>	<u>Clothing</u>
D	Battle dress only
E	Battle dress, body armor, pack
F	Battle dress and body armor
G	Battle dress, body armor, field jacket with liner
H	Battle dress, body armor, field jacket without liner
I	Battle dress, field jacket with liner
J	Battle dress, field jacket without liner
K	Battle dress, pack
L	Underwear, shorts only

The women were dressed in civilian as well as military clothes, namely,

<u>Test</u>	<u>Clothing</u>
Q	Cotton sports wear
R	Cotton dress
S	Wool skirt and sweater
T	Cocktail dress (summer), cotton, nylon, rayon, and other fabrics
U	Cocktail dress (winter), wool
V	Cocktail dress (winter), wool, and coat
W	Nylon underwear
X	Dacron uniform

The underwear used was the same in Tests R to X; in Test Q the underwear was the same except that no slip was worn.

The individuals used in these tests were picked from their records in the tests with the large groups. They included two individuals with exceptionally low and two individuals with exceptionally high charges in the first test. The other individuals were picked more or less at random among the normal individuals.

3. EXPERIMENTAL RESULTS

The results of the measurements at Camp Pendleton are summarized in Figures 5 through 10 and Tables 1 through 5. The charge distribution for the men deviates comparatively little from the Gaussian distribution. The peak of the curve is close to zero charge in the three cases - standing, walking, and running. The average absolute values are given in Table 1. The corresponding curves for the women, Figures 8 through 10, are different in several respects. First of all, the charge is about 300 times that of the men (the $2 \mu\text{F}$ capacitor was used in these tests). The distribution in the cases of standing and walking is bimodal, whereas that in the case of running is almost Gaussian. There is little effect of the state of motion, a peak occurring at about 10 scale units in the three cases. The bimodal distribution is believed to be caused by two types of step, a long military step and a short civilian step. The short step is not used in running. The average absolute values are given in Table 1.

Table 1. Average Absolute Charges in 10^{-9} C.

	<u>Standing</u>		<u>Walking</u>		<u>Running</u>	
	in	out	in	out	in	out
Men	0.348	0.385	0.385	0.315	0.366	0.268
Women	77.6	124.7	95.9	152.8	121.5	199.7

The charges of the 10 men and 11 women are listed in Tables 2 and 3. The values given for each individual are those for entering from standing, from walking, and from running. The absolute averages for all individuals in each table are given at the bottom of the table. The charges are expressed in scale units at a setting of 3 volts for full scale deflection. The charges in Coulombs are obtained from these values by multiplying by 0.15×10^{-9} . Exceptions are columns X and M in Table 3, for women in uniform, and the values for No. 112 R which were obtained with the $2 \mu\text{F}$ capacitor inserted and at a setting of 0.3 volts for full scale deflection. These values are converted into Coulombs by multiplying by 12×10^{-9} . The men were all dressed the same and as given on Page 6. The women had individual variations within the general group of clothing; the characteristic garment of each individual is given in Table 4.

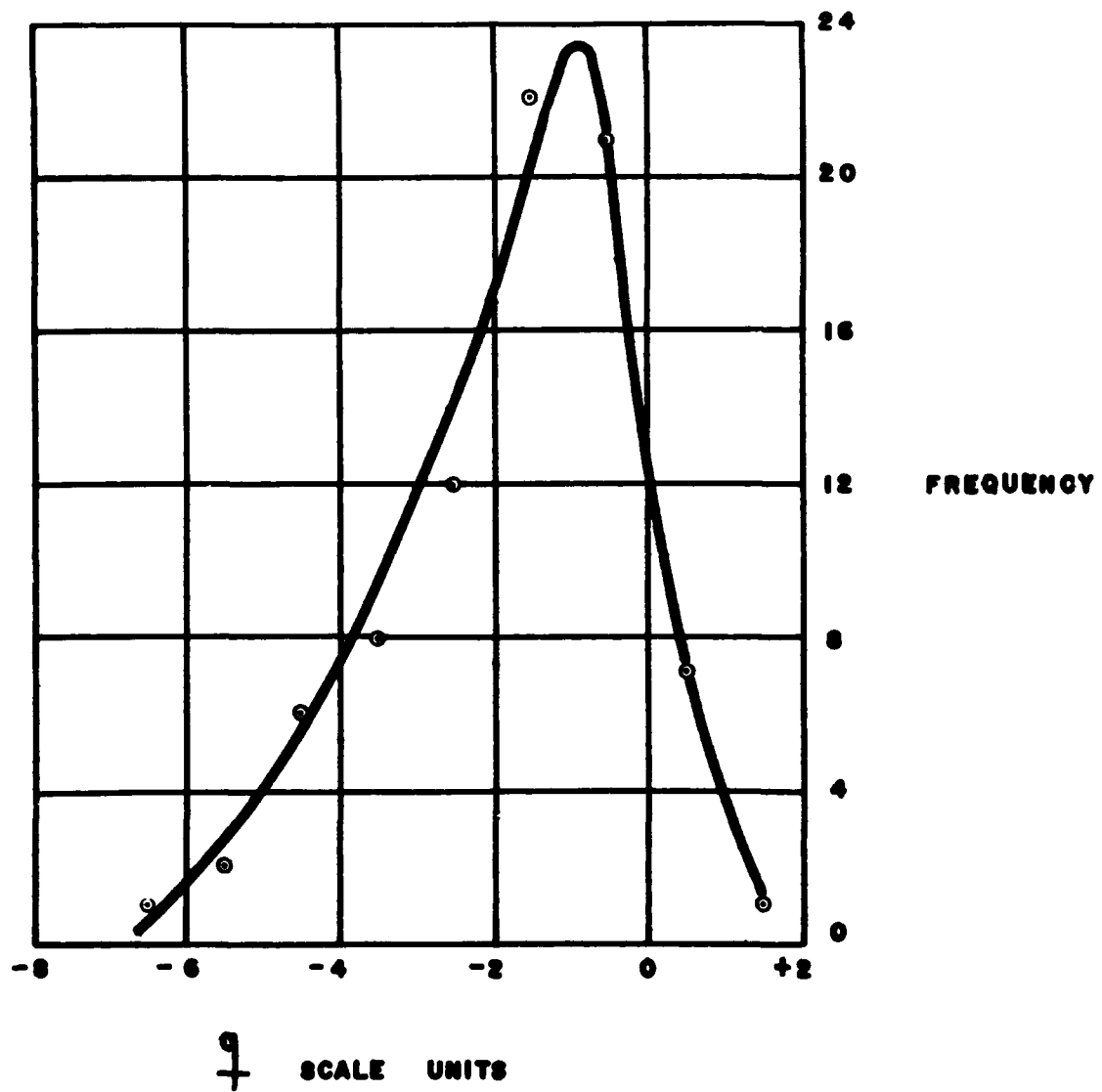


Figure 5. Charge distribution curve for 75 men in battle dress entering the cage from standing.

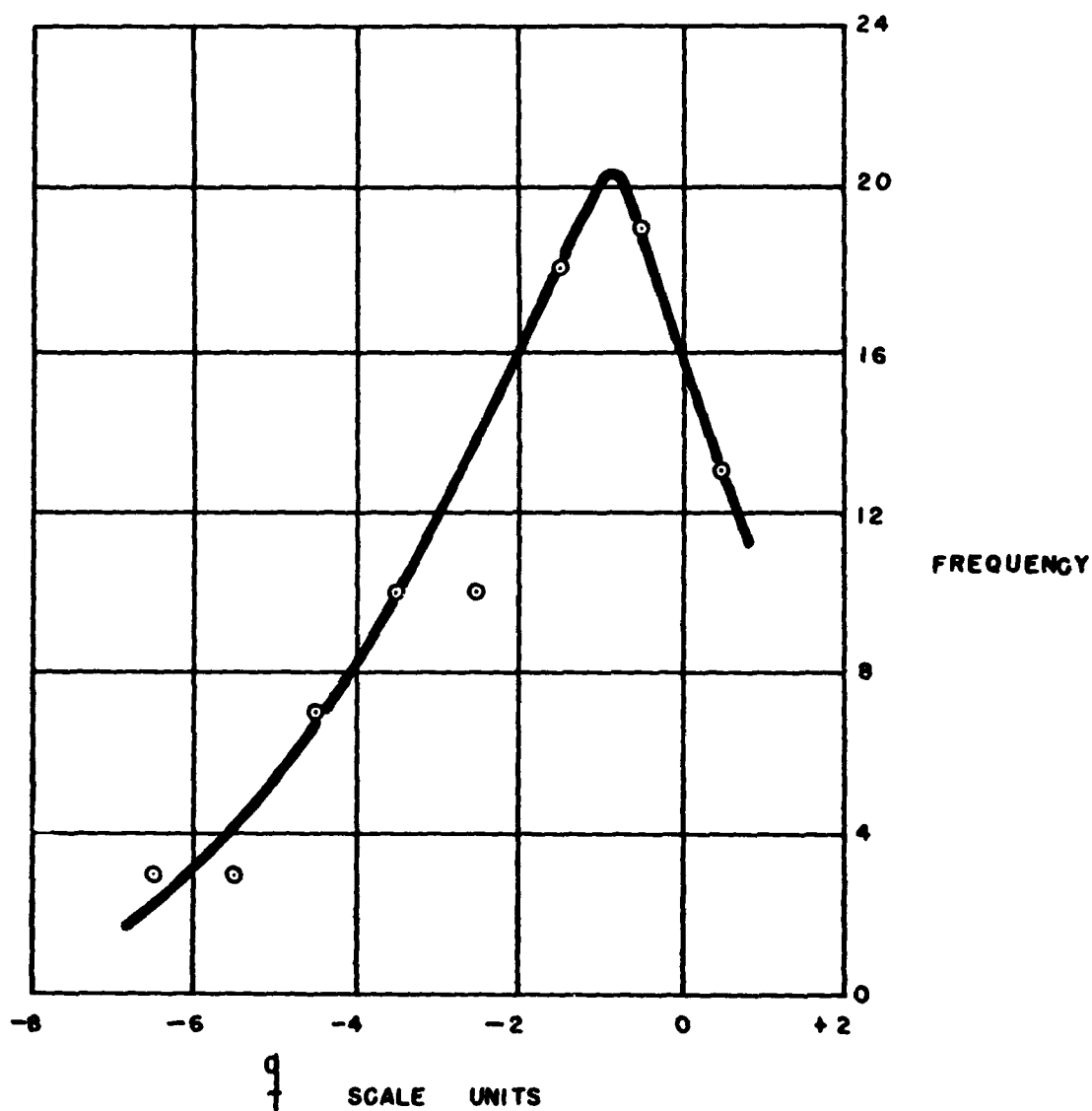


Figure 6. Charge distribution curve for 75 men in battle dress entering the cage from walking.

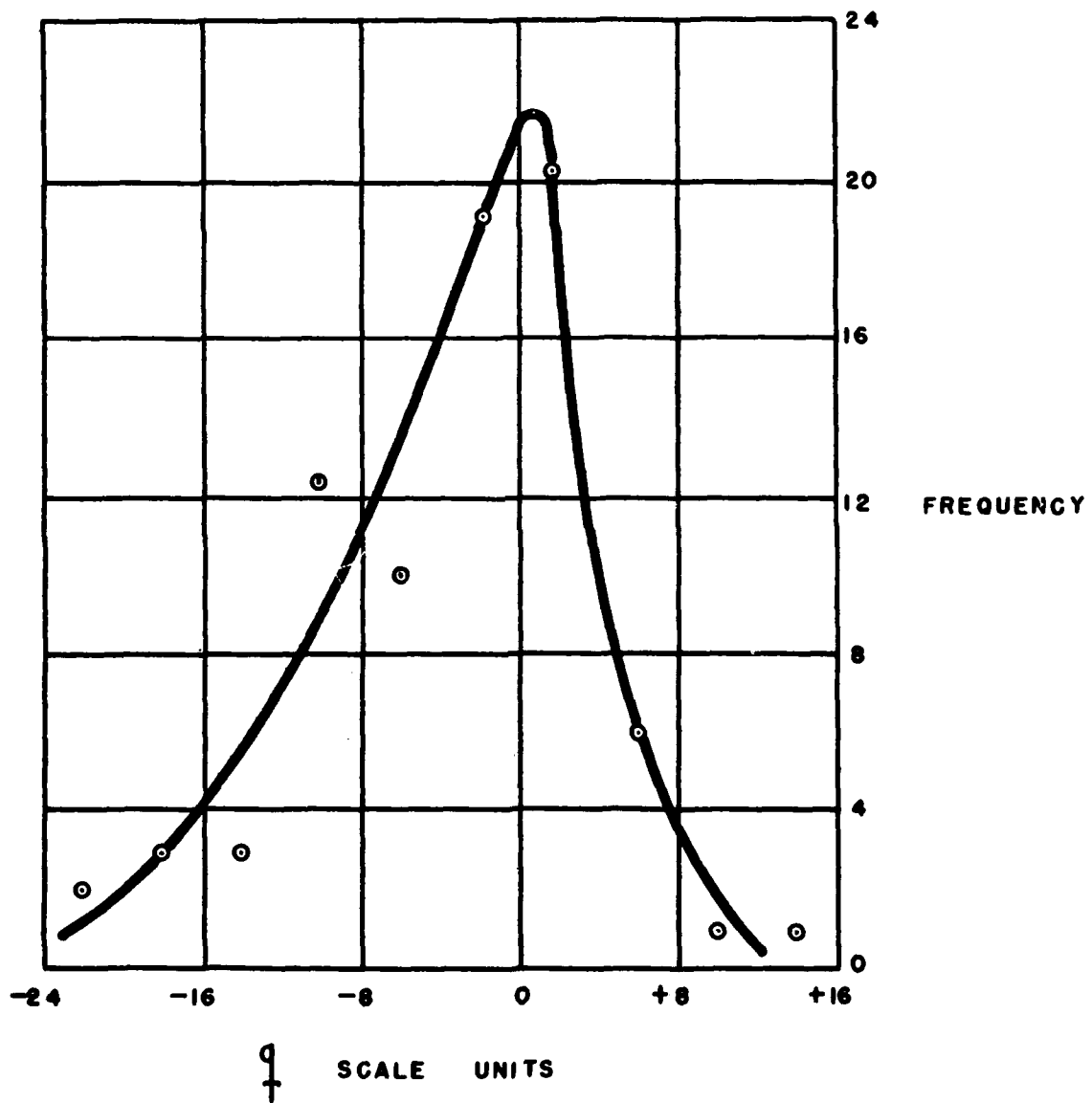


Figure 7. Charge distribution curve for 75 men in battle dress entering the cage from running.

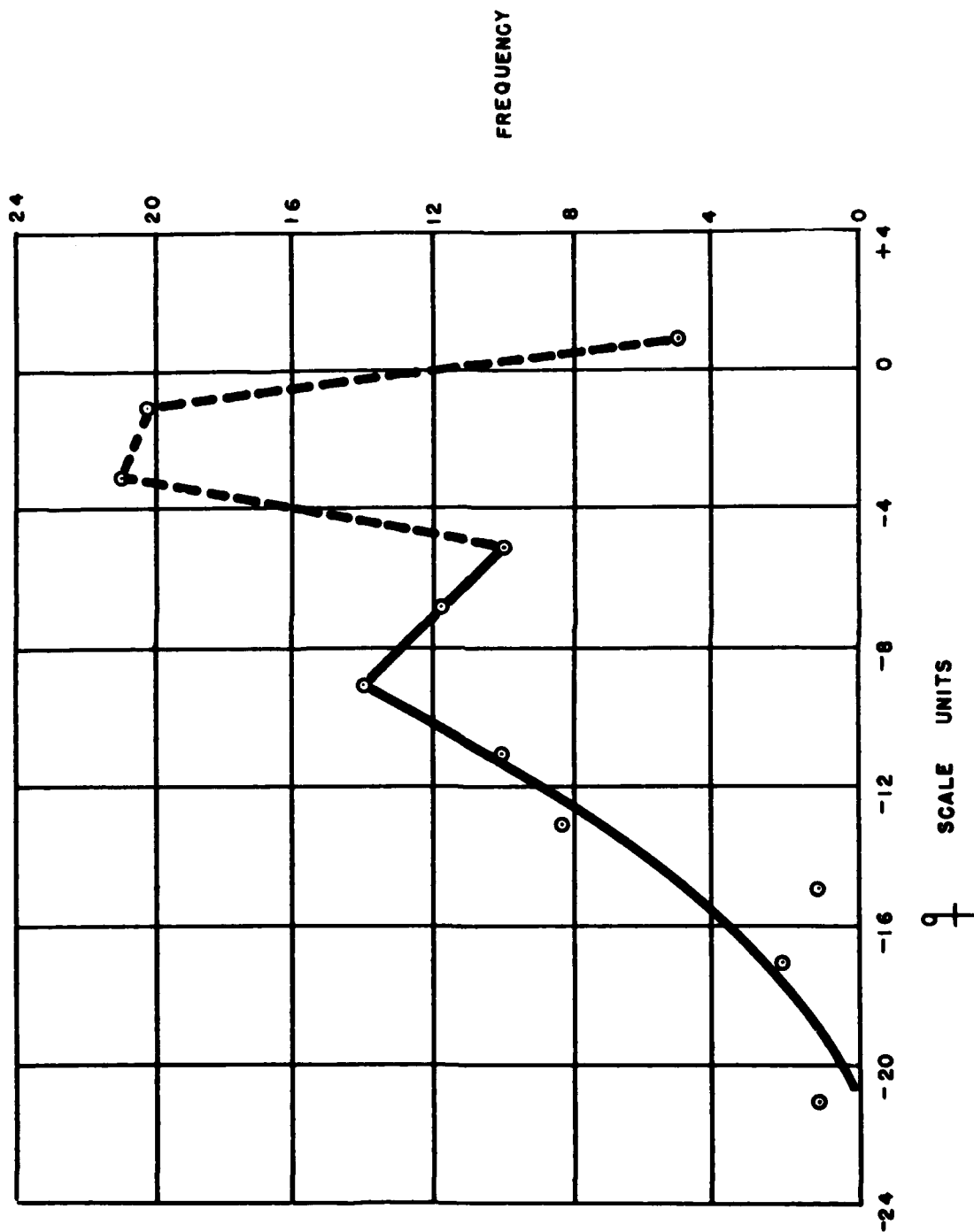


Figure 8. Charge distribution curve for 100 women in dacron uniform entering the cage from standing.

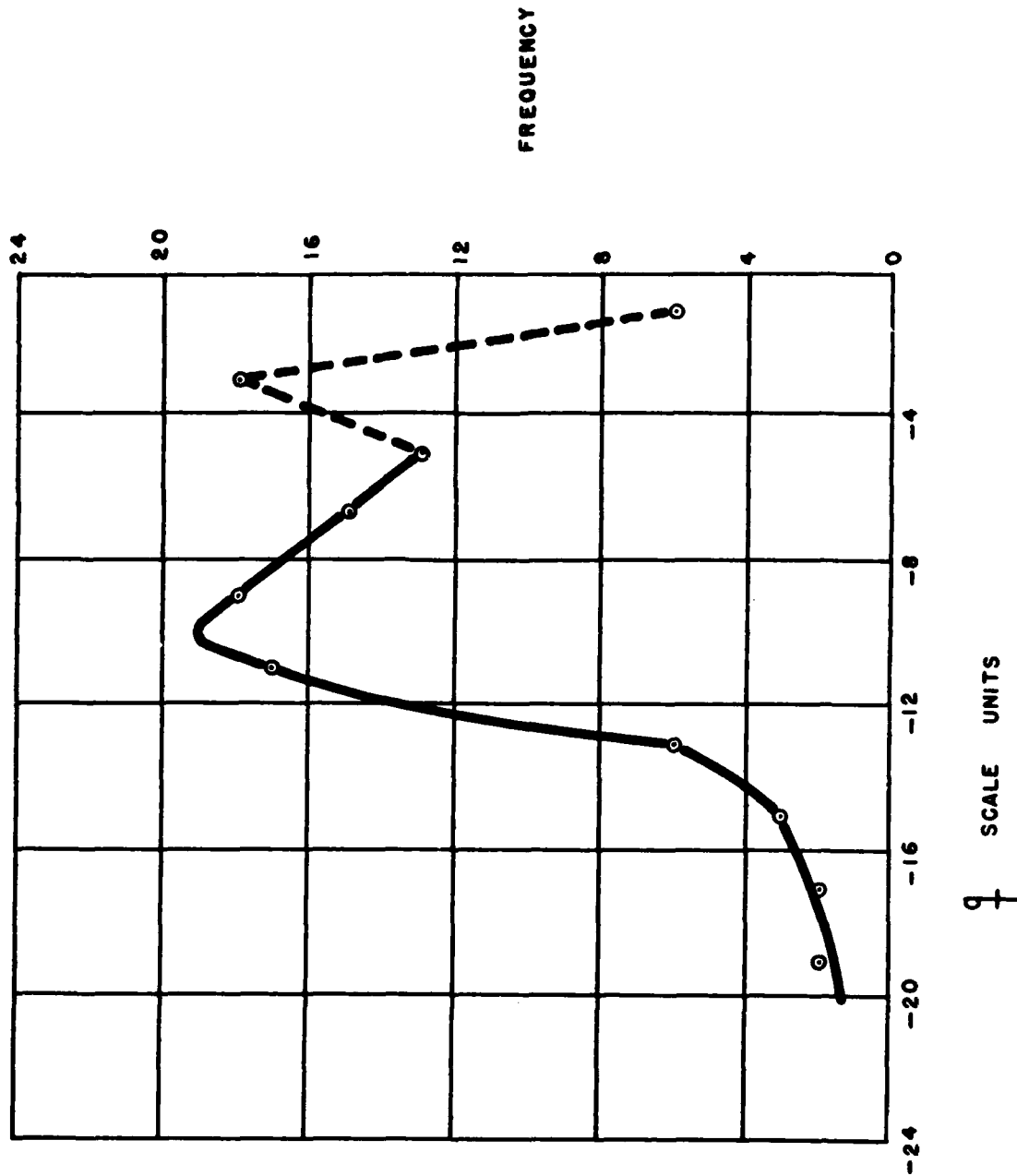


Figure 9. Charge distribution curve for 100 women in dacron uniform entering the cage from walking.

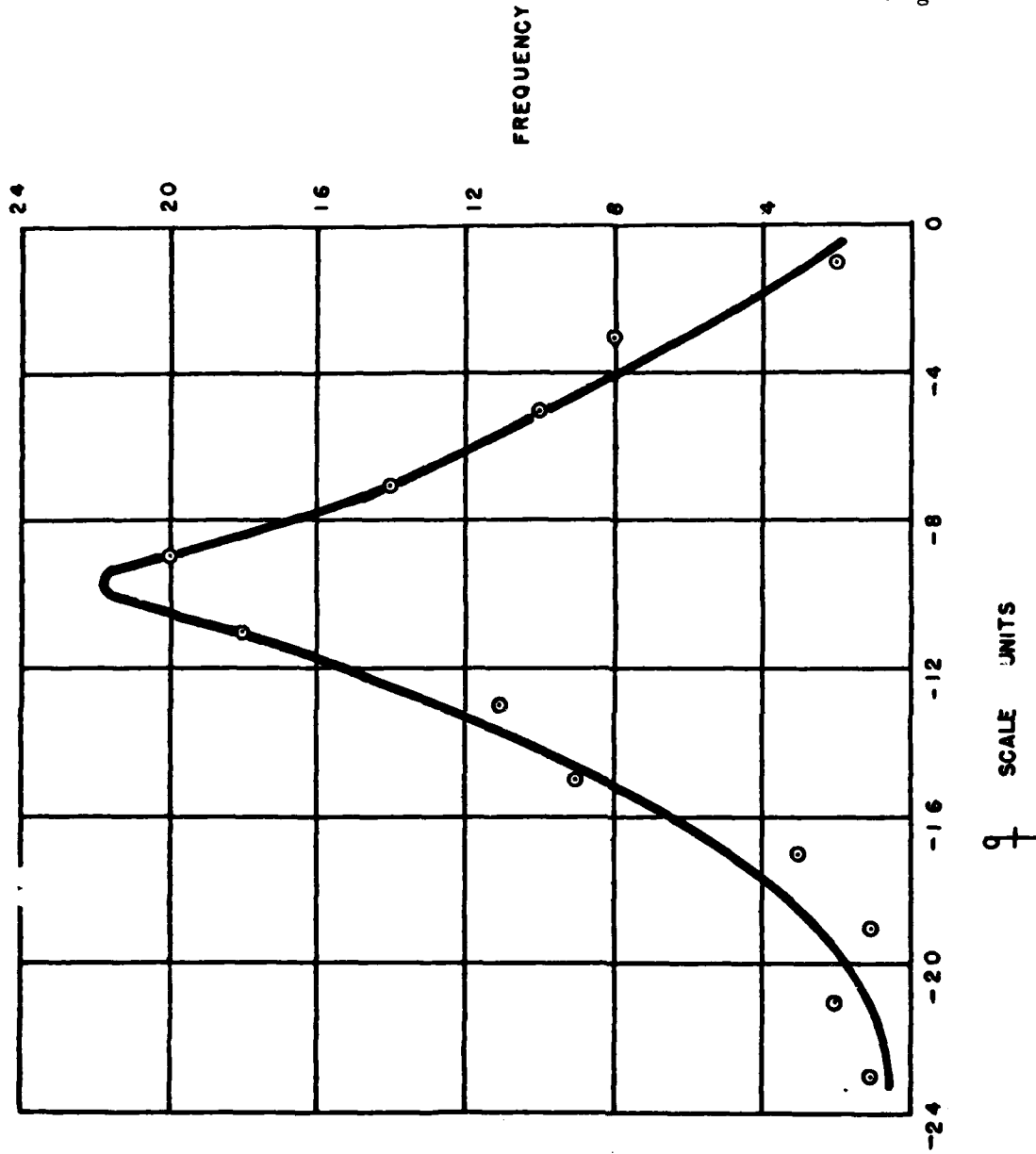


Figure 10. Charge distribution curve for 100 women in dacron uniform entering the cage from running.

Table 2. Charges on 10 Men (Tests D through L).

No.	D	E	F	G	H	I	J	K	L
13	-2.0	-2.0	-2.5	-1.5	+1.0	-4.0	-6.5	-5.0	-5.5
	0	-	-5.0	-	-	-	-	-6.5	-
	-1.0	-	-	-7.5	-1.5	-3.0	-0.5	-5.0	-
15	-15.5	-2.5	-1.0	-3.0	-2.5	-3.0	-3.0	-3.0	0
	- 2.0	-	-3.0	-	-	-	-	-2.5	-
	- 4.0	-	-	-5.5	-4.0	-0.5	0	-2.0	-
23	-25.0	+1.0	-1.0	-1.0	-1.0	-1.0	-2.0	-1.0	-5.0
	- 2.5	-	-2.0	-	-	-	-	+1.5	-
	- 4.5	-	-	-2.0	+1.0	-1.0	-1.0	-2.0	-
36	-1.0	-1.5	-3.0	-2.5	-1.0	-1.5	-1.0	-2.0	-5.5
	-1.0	-	-1.5	-	-	-	-	-1.0	-
	0	-	-	-2.0	-1.5	-0.5	-1.0	-1.5	-
40	-3.0	-4.5	-3.5	-4.0	-4.0	-4.0	-5.0	-6.0	-5.0
	-4.0	-	-3.0	-	-	-	-	-9.5	-
	+2.7	-	-	+1.0	0	0	0	-1.0	-
47	+2.0	-2.0	-1.0	+0.5	-1.0	+1.0	-0.5	-1.0	-5.0
	-4.0	-	-2.0	-	-	-	-	-3.0	-
	+4.2	-	-	0	0	-1.5	0	-1.0	-
51	0	-2.0	-2.0	-1.5	-2.0	-2.0	-2.0	-2.5	0
	-2.0	-	-1.0	-	-	-	-	-3.0	-
	-0.3	-	-	0	0	0	0	0	-
62	-1.0	-7.5	-6.0	-5.5	-6.0	-3.5	-4.0	-4.5	-5.5
	-4.0	-	-5.0	-	-	-	-	-5.0	-
	-11.0	-	-	-9.5	-8.0	-5.5	-9.0	-12.5	-
90	-6.0	-4.5	-6.0	-4.5	-5.5	-3.5	-5.5	-5.0	-6.5
	-4.5	-	-4.5	-	-	-	-	-4.5	-
	-4.3	-	-	-2.0	-2.0	-5.0	-1.5	-6.5	-
94	-5.0	-4.5	-6.0	-6.0	-4.0	+1.5	-2.0	-3.0	-6.5
	-5.0	-	-3.0	-	-	-	-	-2.0	-
	-3.7	-	-	-8.0	-7.0	-4.5	-3.5	-5.5	-
Average Absolute Charge	6.1	3.2	3.4	3.0	2.8	2.5	3.2	3.3	5.5
	2.9	-	3.0	-	-	-	-	-	-
	3.6	-	-	3.8	2.5	2.2	1.7	3.7	-

Table 3. Charges on 11 Women (Tests M, and Q through X).

No.	Q	R	S	T	U	V	W	X*	M*
112	-26.0	- 7.5*	- 8.3	-12.7	+31.7	-16.7	+60.0	- 6.0	-10.0
	-22.5	-11.0*	-13.3	+25.0	+16.7	-44.0	+39.3	- 5.2	-12.5
	-43.3	- 9.2*	-13.3	-23.3	+23.3	+25.0	+46.7	- 7.2	-16.0
115	+ 3.0	+ 6.0	+ 6.7	+11.7	+ 3.3	+13.3	+ 8.3	- 6.0	- 8.0
	+ 8.5	+ 8.0	+ 6.7	+10.0	+ 6.0	+ 8.3	+28.3	- 7.0	- 9.5
	+13.0	+18.0	+21.7	+ 8.3	+ 8.3	- 5.0	+ 8.3	- 8.5	-10.5
120	+ 2.2	- 1.8	+ 9.3	+19.3	+ 8.3	+ 6.7	-26.0	- 5.0	0
	+ 3.0	+ 9.0	+10.7	-30.0	+15.0	+11.7	+21.7	- 7.5	- 1.5
	+ 5.5	+ 3.0	+10.0	-25.0	+20.0	+19.3	+ 6.7	- 7.0	- 2.0
122	+ 5.8	+ 4.0	+ 8.3	+21.7	+16.7	-	-71.7	-11.0	- 8.0
	+ 5.0	+ 3.0	+10.0	+16.7	+25.0	-	-60.0	- 7.5	- 8.0
	+ 8.8	+ 2.5	+23.3	-13.3	+20.7	-	-31.7	- 7.2	- 9.0
127	+ 2.0	+ 2.0	-11.7	-	-	-	+18.3	- 9.0	-21.5
	+ 3.2	- 5.0	-33.0	-	-	-	-58.3	-14.5	-20.0
	+ 5.5	+ 4.0	-10.0	-	-	-	-50.0	-14.2	-23.0
141	+ 6.5	- 6.5	-	-23.3	-	-	- 3.3	0	0
	+14.0	- 4.5	-	-13.3	-	-	+ 4.0	- 0.5	- 1.0
	+10.0	- 5.0	-	-16.7	-	-	- 8.3	- 1.0	- 1.5
146	- 1.5	+ 2.5	+70.0	- 5.0	+ 6.7	-	+38.3	-10.0	-13.0
	+ 3.5	+ 9.0	+12.7	- 9.3	+ 8.3	-	+ 8.3	- 8.2	-13.5
	+ 4.5	+ 5.0	+33.3	-11.7	+41.7	-	-16.0	- 9.0	-14.5
165	+ 1.5	+ 0.3	+ 6.7	-10.0	+ 9.3	-	+55.0	- 4.5	-12.5
	+ 1.0	+ 4.0	+36.7	-21.7	+30.0	-	+63.3	- 2.5	-17.5
	+ 2.5	- 3.0	+28.3	-28.3	+50.7	-	+46.7	- 3.5	-17.5
181	+ 4.5	-	+ 3.3	- 1.0	-	+ 3.3	-43.3	- 3.0	- 4.5
	- 9.0	-	+ 9.3	- 2.0	-	+ 6.7	-46.7	- 5.5	- 5.0
	- 6.0	-	+10.7	- 2.2	-	+ 7.3	-33.3	- 6.8	- 6.0
195	- 4.0	+ 3.0	+ 3.3	+40.0	-	-	-11.7	0	+ 1.0
	+ 1.0	+ 1.0	+ 8.3	+12.7	-	-	- 4.0	- 1.0	- 0.5
	+ 1.0	+ 1.5	+ 6.7	-30.0	-	-	- 3.3	- 2.0	- 2.5
199	+ 3.2	+ 1.5	+ 6.7	-13.3	+70.0	-	- 5.0	- 7.8	-17.0
	+ 1.2	- 2.0	+15.0	+18.3	+ 6.7	-	-65.0	- 5.0	-17.5
	+ 3.0	+ 5.0	+41.7	-46.7	+ 6.7	-	-63.3	-10.5	-21.5
Average	3.4	3.1	13.4	15.9	20.9	10.0	31.0	5.7	8.8
Absolute	4.9	5.1	15.6	15.9	21.1	14.1	34.5	5.9	9.7
Charge	6.0	5.2	19.9	20.6	24.5	11.3	28.7	7.0	13.1

Charges in scale units. Charges in Coulombs are obtained by multiplying by 0.15×10^{-9} ; for the values marked *, by 12×10^{-9} .

Table 4. Garments Worn in Tests Q through V.

No.	Q	R	S	T	U	V
112	Cotton slacks	Arnel skirt	Wool skirt	Synthetic Dress	Wool dress	Wool dress Jersey coat
115	Rayon jamaicas	Cotton skirt	Wool skirt	Nylon dress (full)	Jersey dress	Jersey dress Cashmere coat
120	Cotton slacks	Cotton skirt (full)	Wool skirt	Nylon dress (full)	Jersey dress	Jersey dress
122	Cotton slacks	Linen dress	Wool skirt	Nylon dress Taffeta skirt	Wool and Jersey dress	
127	Cotton slacks	Cotton skirt	Wool skirt	-----		
141	Cotton slacks	Cotton skirt	-----	Silk dress		
146	Cotton bermudas	Cotton skirt	Wool skirt (full)	Cotton dress	Jersey dress	
165	Cotton slacks	Cotton skirt	Wool skirt	Cotton dress	Wool and Jersey dress	
181	Wool slacks	-----	Wool skirt	Synthetic dress	-----	Synthetic dress Wool coat
195	Cotton bermudas	Cotton skirt	Wool skirt	Nylon dress		
199	Cotton slacks	Cotton dress	Wool skirt	Nylon dress	Wool dress	

It should be noted that large variations in fabric and cut occur within a general type of women's clothing. These variations could not all be included in Table 4. Most fabrics used are mixtures of natural and synthetic fibres. It is possible that the variation in charge within one test may be related to a variation in the proportions of natural and synthetic fibres in the clothes worn by the test objects.

There are a few conspicuous data in Table 3 that are related to the clothes worn. Thus, the Arnel skirt worn by No. 112 in Test R gave a very large charge, comparable to that with the dacron uniform, and 200 times larger than the cotton skirts worn by the other individuals in the same test. On the other hand, the charge of No. 127 in Test R, who had a dacron blouse, was close to the average for the test. This comparison indicates that the lower garment alone determines the charge. That such is the case was shown in laboratory tests to be discussed presently. Another conspicuous charge is that of No. 181 in Test T. This woman had a dress of synthetic fibre that was extremely tight fitting. As a consequence, her step was very short and there was little rubbing of the hem of the skirt against the legs. The large charge of No. 112 in Test Q may be attributable to synthetic fibres (dacron) in her slacks. This point was not checked, however. Conspicuous charges were carried by No. 146 in Test S and by No. 199 in Test U, both when entering from standing only. Their clothes (wool) do not seem to differ from the average in these tests, and the large charge recorded is hard to explain on these observations alone. It was found in the laboratory, however, that wool may occasionally acquire large charges.

The men, being uniformly dressed, showed much less variation than the women, when comparing the individuals within one test. The men were dressed in cotton in all the tests, and their charges were in all the tests close to those of the women in cotton (Tests Q and R). The charge was nearly the same in all the tests with the men. This bears out the view that the charge is determined by the lower garment alone.

Table 5 shows the distribution of polarities in the various tests. On the whole, negative charges were predominant, but positive charges predominated in Tests Q, R, S, U, and V, i. e., with women in cotton or wool clothes. It is noteworthy that among the positively charged men in Test D, only one had a consistently positive charge in the three tests. The factors determining the polarity were studied in the laboratory. They are nature of the other garment and amount of friction.

Table 5. Numbers of Positive, Negative, and Zero Charges.

	Standing			Walking			Running		
Men	+	0	-	+	0	-	+	0	-
D	3	5	67	5	6	64	24	4	47
E	1	0	9	-	-	-	-	-	-
F	0	0	10	0	0	10	-	-	-
G	1	0	9	-	-	-	1	2	7
H	1	0	9	-	-	-	1	2	7
I	2	0	8	-	-	-	0	2	8
J	0	0	10	-	-	-	0	4	6
K	0	0	10	1	0	9	0	1	9
L	0	2	8	-	-	-	-	-	-

Women	+	0	-	+	0	-	+	0	-
M	1	4	95	0	0	100	0	0	100
Q	7	0	4	9	0	2	9	0	2
R	7	3	5	6	0	4	7	3	5
S	8	0	2	8	0	2	8	0	2
T	3	0	7	5	0	5	1	0	9
U	7	0	0	7	0	0	7	0	0
V	3	0	1	3	0	1	3	0	1
W	5	0	6	6	0	5	4	0	7
X	0	0	11	0	0	11	0	0	11

4. SETTLING OF AEROSOL OF CHARGED PERSONS

An exploratory experiment on the settling of aerosol on charged persons was conducted with two volunteers. They were dressed in the uniform of Women Marines, including dacron dress and nylon slip. The charges on these persons were measured and found to be close to the average for the 100 Women Marines.

A mixture of carmine, flower of sulfur, and lycopodium (Buerker's powder) was used as aerosol material. It was placed in a pile on a concrete floor and whirled up by kicking it. Owing to moisture, the particles clustered badly, making the aerosol comparatively coarse, and the separation of positive red carmine and negative yellow sulfur and lycopodium did not occur. Nevertheless, the experiment showed an important effect of charge.

The aerosol settled, of course, on the feet and on the legs. However, there was a peculiar distribution with a heavy deposit up to approximately half knee level, a gradually decreasing deposit up to knee level, and no visible deposit on the legs above knee level. There was a heavy deposit on the inside of the slip at the hem and tapering off up to 2 or 3 inches above the hem. There was also a deposit, although lighter, on the inside of the dress at the hem. Figure 11 shows qualitatively the density of the deposit on the legs as a function of height above the floor.

This experiment shows that electrostatic charge may have a decisive effect upon the settling of charged aerosol. It also indicates a few practical consequences of the effect. First of all, the hem of the skirt, constituting essentially a charged loop, acts as an electrostatic precipitator. The effectiveness of this action cannot be evaluated from this experiment, but it seems reasonable to assume that it would precipitate most if not all small particles, say, below a few microns. Second, the hem of the skirt acts as a reservoir of aerosol, from which it can be transferred to the legs by contact or by loss of charge. It seems conceivable that an electrostatic precipitator in the form of a charged insulator could be used for the protection of nose and mouth against inhalation of aerosols. On the other hand, electrostatic charges on clothes would seem to enhance the vulnerability to skin agents.

5. DISCUSSION

The Faraday cage measures the net charge on the test object. This charge may conceivably be the sum of several charges of opposite polarities. The Faraday cage does not yield any information on the distribution of charge over the body or the various garments. A small net charge may conceivably be accompanied by a large local specific surface charge. These two issues were studied in the laboratory experiments.

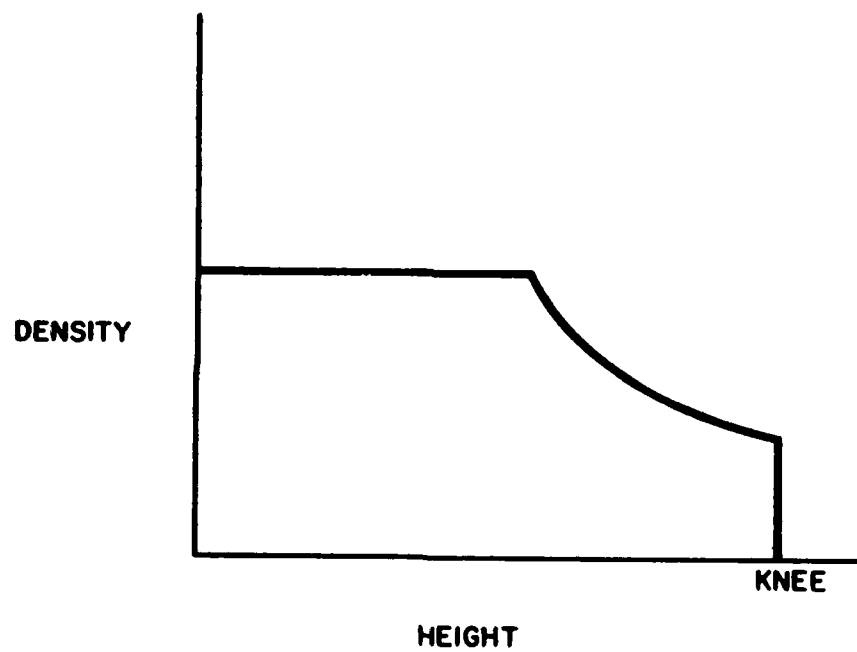


Figure 11. Approximate density of aerosol deposit on leg.

The great difference in charge between men and women in uniform results from a difference in fabric of the uniform. This was shown in laboratory experiments with men wearing suits of dacron or similar materials. The data in Tables 2 and 3 shows that men and women are charged to about the same amount when wearing similar fabrics, e. g., cotton.

The charge is generated at the lowest part of the garment where its friction against the body or other garments is the greatest. Important is thereby friction followed by separation. Thus, there is no measureable charge produced by the friction between body armor and battle dress. This point was further studied in the laboratory. A man wearing a dacron-mixed suit carried a negative charge of about the same magnitude as that of the women in uniform. This charge was reduced by a factor of 5 when the trousers were folded up so that they did not reach the socks. It was reduced by a factor of 100 when they were rolled up tight so as not to rub against the skin. A woman wearing an orlon skirt with the hem below that of the nylon slip had the charge of the women in uniform, but when the skirt was raised above the hem of the slip the charge acquired dropped by more than a factor of 10.

The dacron uniform itself may carry a very large negative charge. A charge more than 10 times that of women in uniform was measured. The large charge occurs after rapid drying or ironing. When the uniform is rubbed against itself, the charge is reduced and may even change polarity. The high charge returns when the uniform is worn. Wool socks rubbed against shoes or trousers and tossed into the cage may carry positive charges of the same magnitude as that of the dacron uniform or suit. Shoes, when tossed into the cage, showed small charges, of the order of those for the men in battle dress and the women in cotton.

Numerous laboratory tests were made with men and women, in which the contribution to the charge by the various garments were measured. This was accomplished by comparing the charge with and without the garment under consideration. These tests show conclusively that only such garments as strike or slide against some other garment or against the skin and then separate, e. g., trousers against socks, skirt hem against leg, contribute to the total charge. There is no relation between the charge of a separate piece of clothing and its charge as worn. On the other hand, synthetic fabrics cause much larger charges than do natural fabrics when worn under conditions conducive to charging. The difference in charge magnitude may easily amount to a factor of 1000.

These results were confirmed by the experiment with the settling of an aerosol, reported in Section 4. The settling pattern indicated a large charge on the hem of the skirt and the legs below the hem of the skirt but little or no charge above that level.

6. CONCLUSION

The experimental results confirm common experience, e. g., the role of the nature of the fabric, the effect of separation of garments, and give, in addition, quantitative measures of the charges produced under the various conditions studied.

An important result is that only such garments as are rubbed and separated contribute to the charge. This concentrates the charge to the lower garments, edge of trousers or skirts. Garments that rub continuously against other garments or the skin, i. e., underwear, do not contribute to the charge. Tight-fitting garments, which do not separate from other garments or the skin, do not contribute to the charge.

The experiment reported in Section 4 confirms the experience of everybody who has operated a coke furnace wearing a nylon shirt: Charged garments attract dust. Charged garments act to aerosols as electrostatic precipitators. The magnitude of the effect has not been studied. The experiments show that the charge and its effect upon settling of an aerosol is localized to the edge of the lower garments, e. g., the hem of a skirt.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) AEROJET-GENERAL CORPORATION Ordnance Division, 11711 Woodruff Avenue Downey, California		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	
		2b. GROUP N/A	
3. REPORT TITLE MEASUREMENTS OF ELECTROSTATIC CHARGES ON MEN AND WOMEN IN VARIOUS CLOTHES (U)			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Special Report			
5. AUTHOR(S) (First name, middle initial, last name) Owe Berg, T. G., Fernish, G. C., and Hunkins, Margaret J.			
6. REPORT DATE 2 November 1961		7a. TOTAL NO. OF PAGES 27	7b. NO. OF REFS 01
8a. CONTRACT OR GRANT NO. DA-18-108-405-CML-829		8b. ORIGINATOR'S REPORT NUMBER(S) 0395-03(08)SP	
8c. PROJECT NO. 4C04-15-029		8d. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) N/A	
10. DISTRIBUTION STATEMENT This document has been approved for public release and sale, its distribution is unlimited.			
11. SUPPLEMENTARY NOTES N/A		12. SPONSORING MILITARY ACTIVITY Directorate of Research Chemical Research & Development Laboratories U.S. Army Chemical Center, Edgewood, Md.	
13. ABSTRACT (U) Electrostatic charges have been measured on 100 men and 100 women in the uniforms of the Marines and the Women Marines and also with men and women in civilian clothes. The charges measured vary by 3 orders of magnitude depending upon the fabric worn. Cotton and wool give comparatively small charges; synthetic fabrics (dacron, orlon, nylon) give comparatively large charges. Charges are generated as a result of sliding contact between garments or between garment and skin, followed by separation. This occurs at the cuffs of trousers and at the hem of a skirt. Other garments contribute negligibly to the charge.			
14. KEYWORDS Electrostatic charges Men Various clothes Women Marine uniforms Cotton Dacron Wool Orlon Sliding contact Nylon Hair combing Seats of automobiles Charge distribution Measurements of, Frequency			

DD FORM 1473

REV 65

REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

23

UNCLASSIFIED

Security Classification